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Analysis of an Experimental Digital Read-outs Slider Crank Mechanism

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***Abstract*—Slider-crank mechanism (SCM) was developed with digital read-outs in this study to make the reading of experimental results more accurate. They are connected by joints and force elements for the conversion of reciprocating motion into rotary motion or vice-versa. A digital protractor (accuracy = ± 0.2) and a digital vernier caliper (accuracy = +0.02 mm) were incorporated as the crank and the slider respectively, while a stainless-steel plate was made the connecting link. The deviation of the slider (displacement) values from the corresponding theoretical values at various angles was determined. The simple harmonic ratio of the analogue mechanism is higher than that of the digital mechanism but the deviations of the slider (displacement) values of the digital mechanism from the theoretical values are quite negligible. The deviations of the analogue system from its corresponding theoretical values are far higher. Based on the result obtained, the digital system is more precise and accurate for experimental studies than the analogue system.**

***Keywords*—slider-crank mechanism, digital and analogue read-outs, linear displacement, reciprocating and rotary motion**

I. Introduction

A mechanism is a mechanical system that transfers motion or energies from the input to the output part of the system [1], [2]. It involves the assembly of links that are connected by joints and force elements such as actuators, dampers, springs, etc. to complete required motion or force transmission. According to [3], and [4], a machine is a combination of resistant bodies compelled to do work with certain determinate motion. Thus, machines can be said to consist of mechanisms. A mechanism is used to produce mechanical transformations in a machine and the transformation could be [5]: converted from one speed to another speed; a torque to another torque; a force to another force; a force into a torque; angular motion into linear motion; linear motion into an angular motion; and an angular motion to another angular motion.

A slider-crank mechanism is a mechanical system that is used in converting reciprocating motion into rotary motion and vice versa. A common example of a slider crank mechanism is an internal combustion engine where the piston motion is converted from linear to rotational as the pressure builds up in the cylinder which drives the piston. The piston's linear motion is converted to the rotational motion of the crank through a connecting rod. The slider crank mechanism is made up of three major parts; the crank, the connecting rod, and the slider. The crank is the rotating disk/part, the slider is the part that moves linearly through a predetermined distance with respect to the rotation of the crank and the connecting link/rod as the name implies joins the other two parts together. There are different types of mechanisms that perform similar operations as the slider crank mechanism among which are the scotch yoke mechanism, the slotted link mechanism, the Whitworth quick return mechanism, the Geneva stop mechanism, etc.

The use of cranks and connecting rods in machine design became abundant in technology from the 16th century [6]. The incorporation of the crank with a connecting rod was used as part of a machine in the Roman Hierapolis saw-mill during the Roman Empire. In modern technology, the slider crank mechanism is of great use in pumps, compressors, steam engines, diesel, and gasoline internal combustion engines. The slider-crank mechanism is utilized in undergraduate engineering courses for the investigation of the machine’s kinematics and resulting dynamic forces. The position, velocity, acceleration, and shaking forces generated by a slider-crank mechanism during operation can be analytically determined [7], [8]. The analytical calculations are often different from experimental data due to certain factors being neglected in the calculations.

Designing a mechanism requires the analysis and synthesis of the various component parts of the mechanism. During analysis, the study of motions and forces concerning the different parts of the mechanism are explained while synthesis involves the design of the different parts of the mechanism based on material selection [9-13]. The function of a mechanism in a machine convert the motion or input force into the desired output. The output force, or motion is linearly proportional to the input in a linearly proportional mechanism while the relationship between the input and the output in some mechanisms is nonlinear. The type, number, length of links, and connectivity of joints determine the mechanism characteristics. Such a mechanism is called a linkage. The linkages are designed in order to decide the position, type of the joints, the length of the links, and how the links are assembled to achieve the desired motion. When analyzing a linkage, a "skeleton diagram" is often used to represent the type of joints, distances between joints, and which joints connect which links in the linkage. This study is aimed at developing and constructing a slider crank mechanism with digital read-outs. This is to ensure that the reading of experimental results is more accurate and effective.

II. Methodology

An in-line slider crank mechanism crank pivot as shown in Fig. 1 coincident with the axis of the sliding motion of the piston pin [5]. Between the extreme positions, the stroke $|\Delta R_4|_{max}$ is defined as the linear distance exhibited by the sliding link. The crank motion (L_2) and connecting arm (L_3) as shown in Fig. 1, is symmetric about the sliding axis. The crank angle needed to cause a forward stroke is the same as the return stroke; causing the in-line slider-crank mechanism to produce a balanced motion.

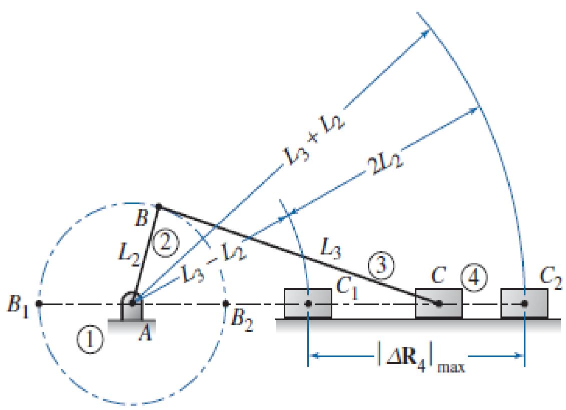

Fig. 1. In-line slider-crank mechanism [1]

An in-line slider mechanism is designed by the determination of the appropriate length L_2 and L_3 to achieve the desired stroke L_4 [7]. The stroke of the in-line slider-crank mechanism as shown in Fig. 1 is twice the crank length; meaning the distance between B_1 and B_2 is of the same distance between C_1 and C_2. The crank length, L_2, can be determined for an in-line slider-crank as illustrated in (1) [7]:

$$L_2 = \frac{|\Delta R4|max}{2} \qquad (1)$$

The stroke of an in-line slide crank mechanism is not affected by the connecting arm length, L_3 but a shorter connecting arm gives a greater acceleration value.

In this study, the digital slider crank mechanism considered was an adaptive idea as it involves the adaptation of existing design with new ideas. The adaptation involves the incorporated digital displays i.e., the digital vernier caliper and the digital protractor.

A. *Dimension of the Various Links*

Length of the crank (L_2) - 52 mm
Length of the connecting arm/rod (L_3) - 140 mm
Length of the slider $|\Delta R_4|_{max}$ - 160 mm

B. *Design Specifications of the Digital Vernier Caliper and Digital Protractor*

1) *Digital Vernier Caliper*

Measuring Range: 0 to 160 mm
Resolution: 0.01 mm
Accuracy: + 0.02 mm
Zero setting at any position. It has a small locking thumb screw which locks the jaws in place.

2) *Digital Protractor*

Specification: 200 mm
Measuring Range: 0 to 360° (degrees)
Resolution: 0.05
Accuracy: $\pm$ 0.2
Zero setting at any position
Strong blade lock to hold the readout securely.

The expression for the determination of the theoretical slider displacement is given in Eqn. (2) [6];

$$X = r[(l - cos\theta) + n - (\sqrt{(n^2 - sin^2\theta)})] \qquad (2)$$

where X = Linear displacement, r = Crank radius = 52 mm, l = Connecting link length =140 mm, θ = Crank angle (in radian)

$$n = {}^{l}/_{r}$$

$$\text{Therefore, } n = {}^{140}/_{52} = 2.69$$

III. Results and Discussion

The experiments with the digital and analogue mechanisms were separately carried out and the data obtained are presented in Table 1 and Table 2, respectively. A similar comparison of results was done in the study of [14, 15]. Table 1 shows the crank angles θ, the digital displacements X_d, theoretical displacements X_t , and the deviation of digital displacement from the corresponding theoretical values $(X_d - X_t)$. Table 2 shows the values obtained from the experiment with the analogue slider crank mechanism where X_a is the analogue displacement, and $(X_a - X_t)$ is the deviation of analogue displacement from the corresponding theoretical values. The graphs of crank angles against the corresponding displacements are also presented in Fig. 2 and Fig 3.

TABLE I. Experimental Data From The Digital Slider Crank Mechanism

S/N	Angle θ (°)	X_d (mm)	X_t (mm)*	Deviation $(X_d - X_t)$ mm

1.	0	0.00	0.00	0.00
2.	30	10.09	9.41	0.68
3.	60	34.48	33.46	1.02
4.	90	62.77	62.05	0.73
5.	120	86.15	85.47	0.68
6.	150	100.11	99.49	0.62
7.	180	104.69	104.00	0.69
8.	210	100.23	99.44	0.79
9.	240	85.99	85.38	0.61
10.	270	62.02	61.92	0.10
11.	300	32.84	33.33	0.43
12.	330	8.80	9.32	0.52
13.	360	0.01	0.00	0.00

X_d = Digital displacement, X_t* = Theoretical displacement (calculated using Q-Basic Programming application)

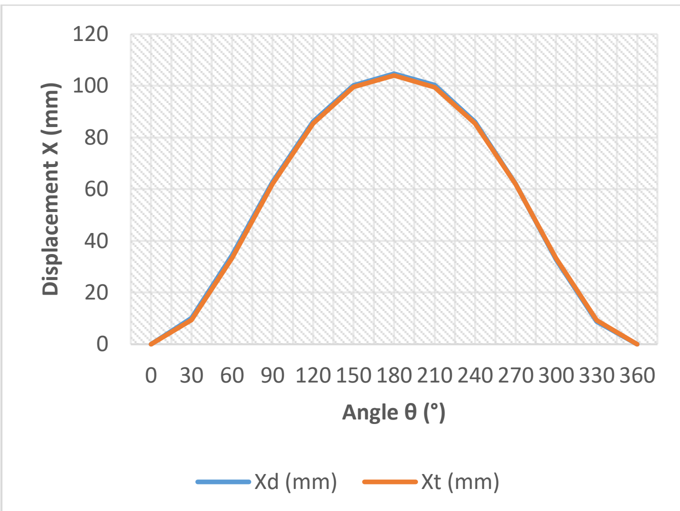

Fig. 2. Digital and theoretical slider displacements against crank angle

TABLE II. EXPERIMENTAL DATA FROM ANALOGUE SLIDER CRANK MECHANISM

S/N	Angle θ (°)	X_a (mm)	X_t (mm)*	Deviation ($X_a - X_t$) (mm)
1.	0	0	0.00	0.00
2.	30	5	5.73	0.73
3.	60	14	20.52	6.47
4.	90	27	38.55	11.53
5.	120	38	54.02	16.00
6.	150	47	63.76	7.81
7.	180	49	66.99	18.00
8.	210	47	63.73	16.75
9.	240	41	53.96	13.00
10.	270	31	38.46	7.53
11.	300	18	20.43	2.50
12.	330	6	5.67	2.43
13.	360	0	0.00	0.00

X_a = Analogue displacement, X_t = Theoretical displacement (calculated using Q-Basic programming application)

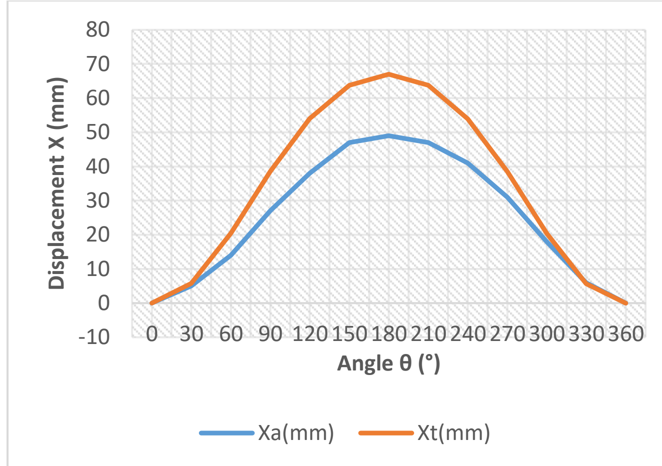

Fig. 3. Variation of analogue and theoretical slider displacements against crank angle

From Fig. 2, it is deduced that the digital displacements are very close to the theoretical values which shows a high level of accuracy of the digital slider crank mechanism.

For the analogue slider crank mechanism,
Crank radius, r = 33.5 mm
Connecting link length, l = 114 mm

$$n = {}^{l}/_{r}$$

$$n = {}^{114}/_{33.5} = 3.4$$

Fig. 3 shows the graph of the analogue and theoretical displacements against the crank angles. There is a large disparity between the displacement values and this shows the ineffectiveness of the analogue system.

For the digital system, the mean deviation is 0.5. While for the analogue system, the mean deviation is 7.90. Comparing the mean deviations, it is seen that the mean deviation of the analogue system is greater than that of the digital system showing that the digital system is of higher accuracy and higher precision.

IV. CONCLUSION

From this study, the results revealed that the slider crank mechanism with digital readouts gives more accurate data at values of theta (θ) below 120° and values above 240° when compared with the theoretical equivalents. However, slight discrepancies are observed in the values of displacement for the values of theta between 120° and 240°. There are also large disparities between the values from the analogue mechanism and the theoretical values. Also, it is deduced that there are positive deviations in the digital displacement values from the theoretical displacement values, unlike the analogue displacement values which negatively deviate from their theoretical values. This deviation is useful in the experimental analysis of the compression ratio of an internal combustion engine. The positive deviation shows the need for clearance while the negative deviation shows a shortage in the compression ratio.

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